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TESTING OF PHOTOVOLTAIC MODULES
UNDER PULSED SIMULATED SUNLIGHT

J. AYER

FEBRUARY 1984

THE UNIVERSITY OF

CHICAGO

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ABSTRACT

This report describes a large area pulsed solar simulator located at the Division of Electrical Engineering, National Research Council of Canada, Montreal Road, Ottawa, Ontario, for comparison testing of photovoltaic modules for their electrical performance. The operational set-up of the simulator is relatively simple and quickly produces printed I-V curves with computed data. The test is done under referenced conditions of insolation, temperature, and load and is essentially for performance comparison of similar modules from single or multiple sources. **IT IS NOT MEANT AS A CALIBRATION TEST.**

RÉSUMÉ

Le présent rapport décrit un simulateur solaire à impulsions de grande superficie utilisé à la Division de génie électrique du Conseil national de recherches du Canada, chemin de Montréal à Ottawa (Ontario), pour comparer, par des essais, la performance électrique de modules photovoltaïques. Le simulateur est relativement simple à monter et il produit rapidement des courbes I-V imprimées avec des valeurs calculées. Les essais sont réalisés dans des conditions d'ensoleillement, de température et de charge de référence, et ils servent essentiellement à comparer la performance de modules similaires à partir de sources simples ou multiples. **ILS NE SONT PAS DES ESSAIS D'ETALONNAGE.**

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INTRODUCTION

With the advent of increasing space probe spin-offs for terrestrial usage, components and systems require extensive accelerated and aggravated solar environment testing during the design stages. One of the most prolific devices, the photovoltaic solar cell, now extensively used in terrestrial electrical power systems, requires such detailed testing under a simulated solar spectrum for performance optimization (1).

The increasing use of terrestrial photovoltaic power systems demands a precise and steady state light source whose intensity and spectrum composition is close to that of natural sunlight. This is an important requirement during the design stages of the photovoltaic cells, panels, and power system test models. This report describes operational characteristics of a commercially-available large area pulsed solar simulator (manufactured in the United States) used for production/development testing of photovoltaic modules. The object of this equipment is essentially to support Research and Development activities in photovoltaics in both the private and public sectors in Canada.

DESCRIPTION OF THE SOLAR SIMULATOR (2)

The solar simulator is suitable for measuring the I-V characteristic of large area solar panels. Light is produced using a pulsed xenon source which flashes at twice ac line frequency. One data sample along the I-V curve is taken during each flash. This relaxes the performance requirements of the light source and the electronic load.

The simulator is self-contained and occupies a floor footprint of only 2.29 m x 1.22 m (7.5 ft x 4 ft). The panel is placed in a drawer and is exposed to the light when the drawer is closed. During illumination, the electronic load scans the I-V curve in 6-10 s and output is displayed on a pen plotter. Alternately, the digital panel meters on the load can be interrogated to give V_{OC} , I_{SC} , and light level. An auxiliary digital panel meter provides the temperature of the panel back surface or the standard cell used to calibrate the light level.

The simulator can accept panels with a wide range of voltages and

currents. Low voltage panels can also be handled, although the user must exercise some care in the connections to avoid series resistance in the contacts. Separate sense and current lines are available, as well as a variety of user-selected connectors.

The standard cell is mounted in a standard JPL mount with an integral thermocouple. A temperature controller (Peltier plus water cooled) is used to maintain a fixed 28°C on the cell for maximum calibration accuracy. The standard cell, which is used to define the absolute light level, can be adjusted in height to match the solar panel. It is located immediately beside the panel to be tested.

The drawer assembly consists of three moveable rails on which the panel is placed. The function of the rails is to provide uniform support despite any configuration of protruding connectors or packages on the underside of the panel. Moveable bumpers are used to assist in placing all panels in the same position in the drawers for maximum repeatability.

Computer Interface

A computer is provided for test data acquisition and processing. In addition to the conventional data produced by the electronic load, the computer also generates fill factor, apparent series resistance, and voltage and current at the maximum power point. The computer is also programmed to generate temperature and insolation-corrected I-V curves, given the correction coefficients for the type of panel being measured. Programs are available to assist in obtaining the temperature correction coefficients and other parameters.

The computer, an HP-85, has an integral CRT graphics display, paper printer/plotter, and high speed magnetic tape. In addition to I-V data, there are also a caption, time-of-day, date, and serial number (with auto increment capability).

An unusual capability of the software package is the production of statistical histograms which display the performance trends for various parameters of a group of panels. Available for analysis are V_{oc} , I_{sc} , FF , I_{mp} , P_{mp} , and R_s for the selected panel temperatures (Fig. 1). Standard deviation and totals outside of 3 σ are also provided (Fig. 2). Hard copy plots are available for all these data. All computer-corrected I-V curves can be reproduced on either the large plotter or the smaller unit in the HP-85.

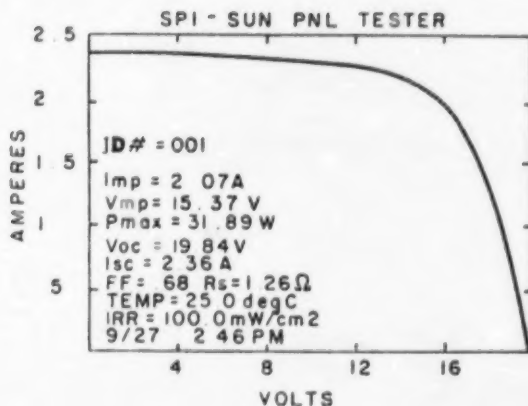


Figure 1. I-V curve and measured values of various parameters

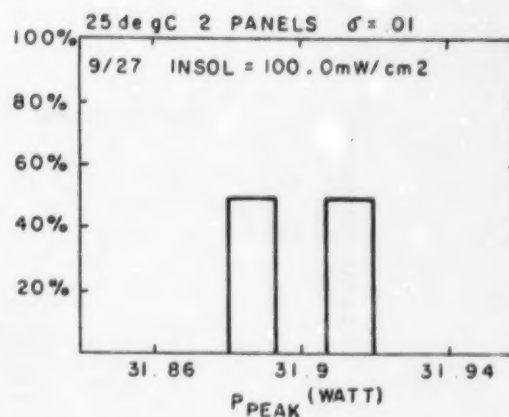


Figure 2. Standard deviation of similar PV modules

SIMULATOR CHARACTERISTICS

Light source:	pulsed xenon 10% duty cycle
Spectrum:	air mass ~1.5 (proposed ASTM E 44.02 global standard), see Fig. 3
Intensity:	variable 70 to 160 mW/cm ²
Standard cell:	calibration traceable to U.S. National Bureau of Standards, type II. Diffused junction silicon.
JPL Mount	Temperature maintained at 28 ± 1°C
Test plane:	80 cm × 135 cm × 8 cm (~32 in. × 52 in. × 3 in.)
Uniformity:	±5%
Power capacity:	35 V and 15 A

The standard tests are performed on a photovoltaic module to obtain:

- I-V curve (Fig. 1)
- V_{oc}
- I_{sc}
- I_{max} at peak power
- V_{max} at peak power
- R_s series resistance of the PV module
- fill factor (FF)
- temperature of the back plane of the module

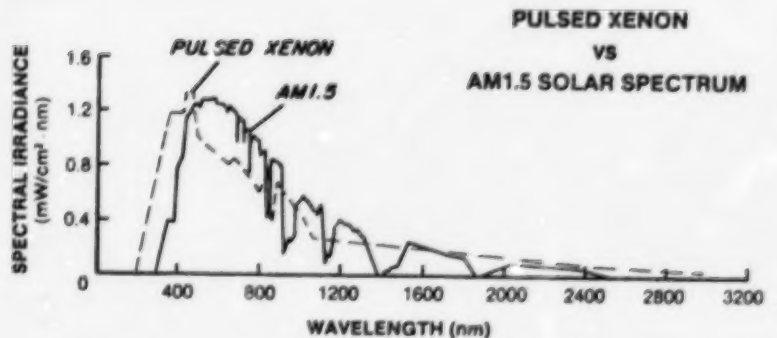


Figure 3. Spire simulator spectrum at air mass ~1.5

PERIODIC SIMULATOR CALIBRATION TESTS

Intensity

The simulator is periodically checked for performance deterioration by testing a reference PV panel (Reference Panel - Phillips Model BP X 47A) under identical conditions of insolation, temperature, and load. This panel is maintained as a reference test panel. See comparison tests with ORP tested modules in Table 1.

Uniformity of Irradiance

In order to verify the uniformity of the simulated insolation in the total area available for module window (80 cm x 135 cm), a wooden tray with 45 "pigeon holes" was designed (Fig. 4). A single PV cell with a thermocouple is placed in each pigeon hole and V_{OC} , I_{SC} , and $T (^{\circ}C)$ are measured under constant intensity and within $\pm 1^{\circ}C$, using a peak-voltage-hold circuit as shown in Fig. 4. The variation of the short circuit current in the pigeon holes indicates the relative non-uniformity of the insolation present (see Fig. 5). The NRC cell was calibrated using an ARCO ASI-124, which was calibrated against six reference standard cells. See Table 2. See p. 6 for details of spire reference cell.

TESTS AVAILABLE FOR INDUSTRY

In most cases, the I-V curves are computed under standard operating

Table 1. Comparison tests with ORF tested modules (3)

	Insolation (W/m ²)	Temperature (°C)	V _{oc}	I _{sc}	FF	V _m	I _m	P _{max}
MODULE 1 (ARCO-MONO)								
ORF	1000	20	17.53	2.32	0.71	14	2.06	28.90
SPIRE	1000	20	17.66	2.27	0.71	14.06	2.02	28.43
Spire reads ~1.6% lower								
MODULE 2 (ARCO-MONO)								
ORF	1000	20	17.66	2.34	0.73	14	2.15	30.12
SPIRE	1000	20	17.77	2.23	0.74	14.01	2.1	29.40
Spire reads ~2.3% lower								
SPIRE REFERENCE MODULE TYPE - STARBURST 001-1130-70 (MONO)								
MIT LL*	1000	30	22.24	3.62		17.5	3.39	59.5
SPIRE	1000	20	21.69	3.76		17.53	3.47	60.87
SOLAREX (POLY) NO: 5								
ORF	1000	20	21.57	2.28	0.64	16	1.96	31.35
SPIRE	1000	20	22.0	2.12	0.65	16.75	1.8	30.22
Spire reads ~3.6% lower								
SOLAREX (POLY) NO: 6								
ORF	1000	20	21.61	2.31	0.65	16	2.08	32.45
SPIRE	1000	20	22.1	2.17	0.67	17.14	1.87	31.97
Spire reads ~1.5% lower								

*SPECTROLAB SIMULATOR

condition (4), i.e., 1000 W/m² at 28 ± 3°C. Other tests (4-6) such as temperature coefficient for current (α), temperature coefficient for voltage (β), and curve correction factor (k) for modules or cells can also be provided.

To enquire regarding tests and costs, please contact:

National Research Council of Canada
Division of Electrical Engineering
Building M-50, Montreal Road
Ottawa, Ontario K1A 0R8

Att: Mr. Gordon Weston, Supply Office
(613) 993-2407

REFERENCE CELL USED IN THE SPIRE SIMULATOR



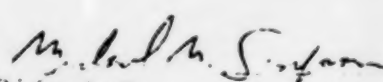
TERRESTRIAL REFERENCE SOLAR CELL
CALIBRATION REPORT

Reference Cell Serial No. SC-007 Date: 4/26/83

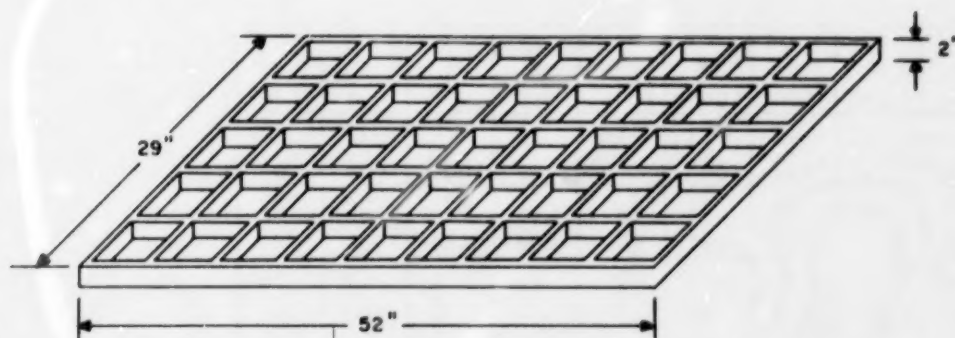
The above mentioned Type II Reference Cell was calibrated under simulated sunlight in accordance with ASTM E130 proposed specification, "Standard Methods for the Calibration of Non-Concentrator Terrestrial Photovoltaic Reference Cells". Calibration was performed against Type I Reference Cell SS-2407 at an incident intensity of 89 to 104 mW/cm^2 and a cell temperature of 28 $^{\circ}\text{C}$.

Calibration Constant = 1.021 $\text{mA}/(\text{mW/cm}^2)$
 $\pm$ 0.006 standard deviation

Temperature Coefficient = 0.049 percent/ $^{\circ}\text{C}$.



Director,
Solar Cell Calibration Laboratory



PEAK DETECTOR

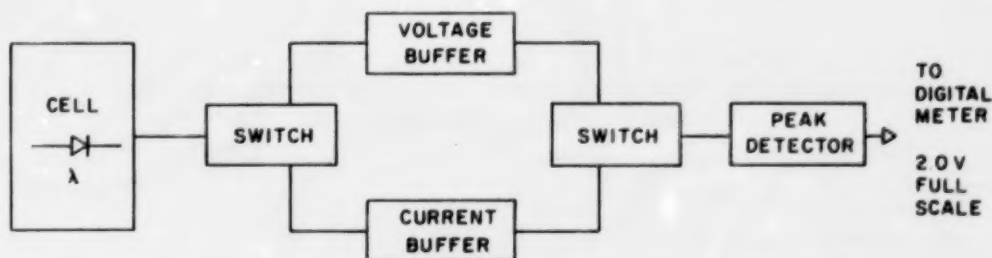
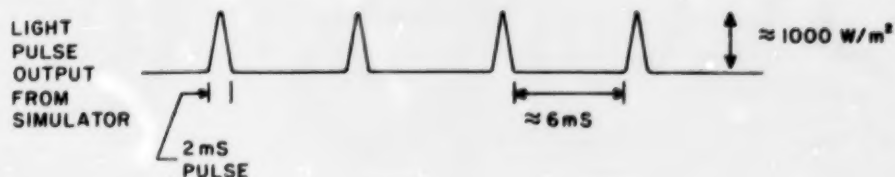


Figure 4. Test set up for uniformity of irradiance

CONCLUSION

The simulator is essentially used for quick comparison of PV module electrical performance. Extrapolated data for different coefficients of temperature, voltage, current, and cell area can also be computed. The test results on the modules compared to the tests by ORF are within 2.3% for ARCO (mono-crystalline), within 3.6% for Solarex (poly-crystalline). The SPIRE reference module test indicates within 1.6% (temperature corrected) with respect to MIT LL test.

1	2	3	4	5	6	7	8	9	+ square number
1016	1016	1000	1008	1008	1016	1008	1031	1008	+ W/m ²
10	11	12	13	14	15	16	17	18	
1000	1016	992	1000	1008	1008	1008	1008	1000	
19	20	21	22	23	24	25	26	27	
984	1016	984	992	992	992	984	1000	1000	
28	29	30	31	32	33	34	35	36	
984	1000	984	992	992	984	976	992	992	
37	38	39	40	41	42	43	44	45	
984	1008	992	992	1000	992	984	992	984	

Figure 5. Verification test for uniformity of irradiance under maximum area of irradiance. The irradiance value (W/m²) in each square (pigeon hole) is calculated from the short circuit current of the single cell based on 1.16 A at 920 W/m² of solar insolation (ref. Haenni solar meter - Model 118 tested under solar irradiance) and at 25°C. Non-uniformity (7) is:

$$\begin{aligned}
 \text{Non-uniformity} &= \frac{\text{IRR}_{\text{max}} - \text{IRR}_{\text{min}}}{2 \times \text{IRR}_{\text{avg}}} \times 100 \\
 &= 2 \times \frac{55}{998.244} \\
 &\approx 2.8\%
 \end{aligned}$$

Table 2. Round-robin standard cell test

JPL Ref. cell	JPL calib	JPL test of ASI-124	%Δ from average of calibration
YB-451	94.9	100.11	+0.4
VS-417	92.8	99.05	-0.66
SS-1440*	130.9	99.88	+0.17
RS-425	120.5	100.31	+0.60
MS-431	132.8	100.11	+0.40
JQ-420	104.1	98.81	-0.90
avg = 99.71			

*JPL has selected SS1440 as its AM 1.5 simulator standard as best average cell for all measurements of Czochralski cells/modules

Uncertainties in Measurements

Some of the uncertainties may be due to:

- spectral irradiance mismatch of simulator and sunlight (5, 8)
- spectral responsivity mismatch between standard cell and test module (6)
- mismatch of series resistance of individual cells in the module (7)
- errors associated with measurement of (a) voltage, (b) current, (c) temperature
- non-uniformity of simulated irradiance on the test area (1)
- deterioration of simulator irradiance with time (1)

ACKNOWLEDGEMENTS

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REFERENCES

1. J. Ayer. The spectrum simulation of the stochastic sun. To be published.
2. Spire Corporation, Bedford, MA. Product description.
3. J. McClung and M. Westcott. Experimental study on photovoltaic module testing methodology. Contract Serial No. OSX81 - 00136. ORF. May 1983.
4. CSA Draft Standard F 380, Photovoltaic modules. 7th Draft. September 1983.
5. H.B. Curtis. Errors in short circuit measurements due to spectral mismatch between sunlight and solar simulators. NASA CR-2010 - N77-20020. 1976.

6. C.H. Seaman. The correction for spectral mismatch effects on the calibration of a solar cell when using a solar simulator. NASA CR-164074 - N81-20546. 1981.
7. Terrestrial photovoltaic measurement procedures. ERDA/NASA/1022-77-16, NASA TM 73702. June 1977.
8. H.B. Curtis. Indoor and outdoor measurements of performance of photovoltaic arrays. NASA CP-2010. N77-200026. 1976.